ON PERFORMANCE OF MODIFIED TORUS INTERCONNECTION NETWORKS

Synopsis submitted in fulfillment of the requirements for the Degreeof

DOCTOR OF PHILOSOPHY

By

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May, 2018

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ABSTRACT

The performance requirements of many applications such as weather predictions, signal processing, image processing and radar tracking, far exceed the capabilities of single processor architecture. The primary components of the digital system are the processing elements, memory units and interconnection networks that connect them. So, to resolve this problem, parallel machine comes into existence where a single problem is break down into parallel tasks that are performed concurrently, reducing significantly the application processing time. With the advancement in technology processor and memory units have improved at a fast rate so there is a need to explore the fast interconnection networks. Initially the bus based architecture was used to connect the various nodes but as the number of nodes increased these busses started to become bottleneck, so the dedicated busses were used. This lead to huge mesh of wires and made it difficult to be implemented in the chip. The idea of routing packets came into existence and mesh the topology based on tile architecture was introduced. Further this topology has moved through the large number of variants because of lesser path diversity and higher diameter. Hence to avoid such issues torus topology is introduced which is regular, higher bisectional bandwidth and better path diversity. The Modified X-torus topology solved the drawback of existing topology by utilizing unused port and improving topological properties. The Center Concentrated X-torus topology reduces the hop count between nodes in the network and has helped in reducing the average latency. The proposed topology has made the results comparable to the torus topology. Another effort to get the topology with minimum number of hop count was done by making additional links between corner adjacent nodes to each other. This Hexagonal X-Torus Topology gains better throughput and minimal latency. The generated topology has performed better than the existing two topologies. The performance of the topology has been analyzed using the five traffic patterns that are uniform, neighbor, bit complement, tornado, and hot spot traffic over the factors end to end delay, throughput andaverage hop count.

1 INTRODUCTION

Networking strategy was originally employed in the 1950's by the telephone industry as a means of reducing the time required for a call to go through. Similarly, the computer industry employs networking strategy to provide fast communication between computer subparts, particularly about parallel machines. Interconnection Networks is the key component of any digital systems[1]. In the early phase of development, the wires were routed to connect the various top-level components like processor, memory units and other intellectual properties (IPs) for the communication. Dally introduced the concept of connecting top level components to network that routes packet between them[2]. It was observed that idea of routing the packets reduced the area consumption by 6.6%, reduced the power dissipation by a factor of 10 and propagation velocity by three times. The idea of routing the packet was high accepted and have been used in the various chips like The Intel's Teraflops research chip is based on 10X8 2D mesh having 80 simple cores[3]the 64-node chip 2D mesh of 8X8 from Tilera[4]and the TRIPS processor[5] are based on mesh topology. Another popular variant of mesh was the torus topology which has been used in various commercial and academic computer like HPGS1280, CrayXT3, CrayXT4[6]and the IBM Blue Gene used 3-D topology[7]. The various another variant of the torus topologies were explored by the researchers which varied some of the topological properties that may be degree, diameter, bisection width and edge length. Even though modifying any one of the parameter may affect the performance of the complete networks, still the performance of the interconnection network also depends upon the other factors like the routing algorithm used and flow control mechanism used. The routing algorithms have been classified into various categories and are used according to the need in the specific application and based on the complexity of the hardware used.

1.1 MOTIVATION AND CONTRIBUTION

Interconnection Network (INs) differentiates itself by providing different connections at different points of time, and it thus helps in faster data communication between terminals. INs are used in variety of applications such as switch and router fabrics, parallel multicomputer, multi-processor system, I/O connections, on chip networks etc[8]. Like other networks, it characterizes itself with three aspects like topology, flow control and routing algorithm. The topology[4], [6], [9] of a network refers to the arrangement of shared set of nodes and channels, which are packaged such that it is cost effective along with its ability to achieve good performance. The routing algorithm and flow control help in achieving the required performance. The routing method employed by a network determines the path taken by a packet from a source terminal node to a destination terminal node in the given topology. Flow control dictates which message gets access to a network resource over time.

Therefore, our first research objective focuses on designing a topology that will have a minimum diameter[10]. Further, the links introduced in the topology are based on the Individual's perception. There may exist a probability of placing a better link in the topology. Our second

objective will focus on designing an approach that can be used to reduce distance between the nodes in the topology. Our third objective will focus on identifying the pitfalls in the existing topology and propose the new topology that can work on the simple hardware complexity. Modified D-Torus is a relatively new interconnection network. Modified D-Torus topology is an enhancement of a D-Torus[11] network by adding some Cross Links. Hence, the distant nodes can be reached by using these links with fewer hops compared to the Torus Network. Comparisons with some popular networks such as 2D Mesh, 2D Torus and D-Torus show that Modified D-Torus has shorter diameter, shorter average distance and larger bisection width.

2 OBJECTIVES

Based on the topological properties of network, it is observed that regular degree, smaller network diameter, higher bisectional bandwidth and high path diversity[8] play important role to improve network throughput[12], latency and hop count.

2.1 To convert existing X-Torus topology into vertex symmetrical structure.

The Modified X-Torus topology is improved variants of X-Torus[8], [13] topology. The major drawback of X-Torus topology is that the degree of each node of odd parity is not 6. Only some nodes have degree 6 and others have degree 5. So, toutilize unused port and making this topology into regular, we formulated enhanced version of it. X-Torus and Modified X-Torus topology have been described in the Figure 2.1.1 and Figure 2.1.2.

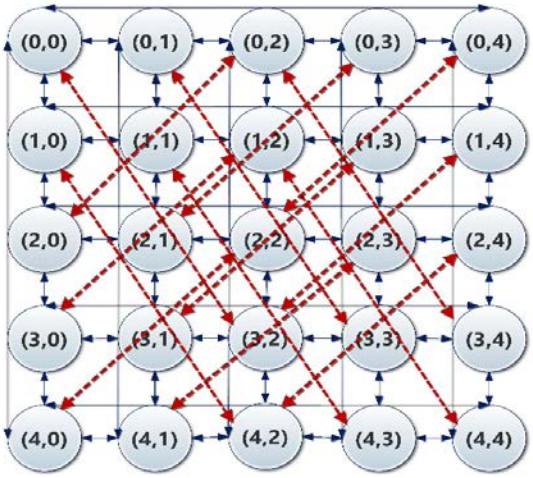

Figure 2.1.1 X-Torus

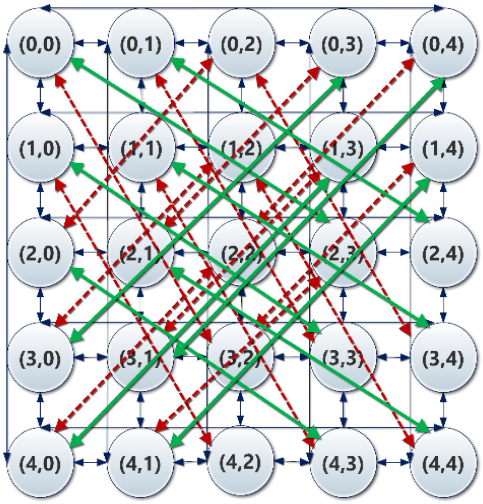

Figure 2.1.2 Modified X-Torus

The performance of all the topologies were compared on the various traffic patterns like a uniform, bit complement traffic, neighbor traffic, tornado traffic and hotspot traffic[14]. The traffic analysis was done on the OMNET++ 4.6simulator[15], [16] on the Windows operating system the details of the simulation parameters have been presented in Table 2.1. The graphs of the end to end delay[14], [17] have been shown in figure 2.1.3 to figure 2.1.7.

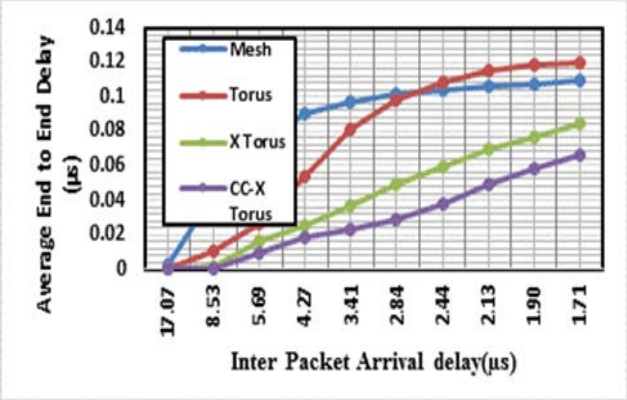

Figure 2.1.3 Average Delay on Uniform Traffic

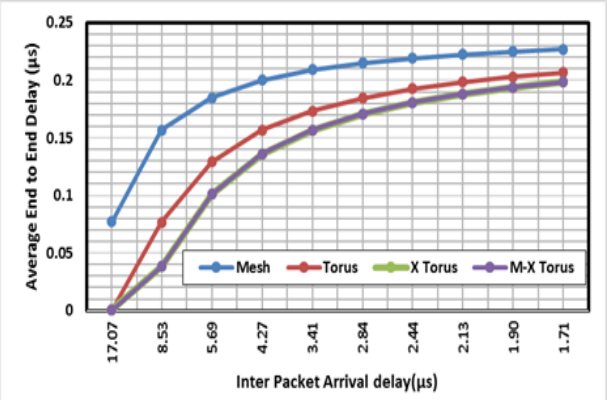

Figure 2.1.4 Average Delay on Bit Complement Traffic

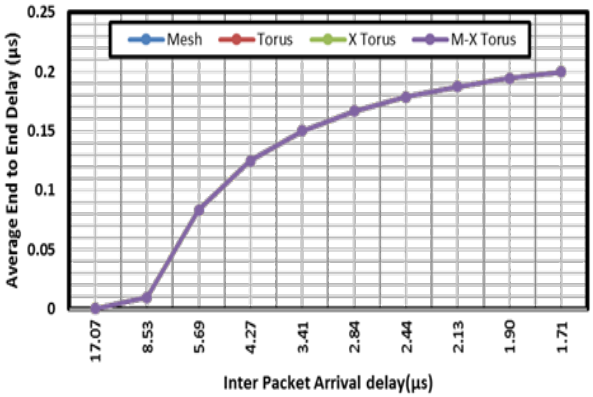

Figure 2.1.5 Average Delay on Neighbor Traffic

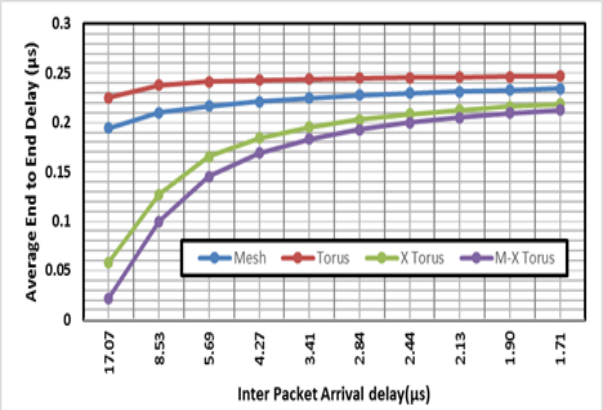

Figure 2.1.6 Average Delay on Tornado Traffic

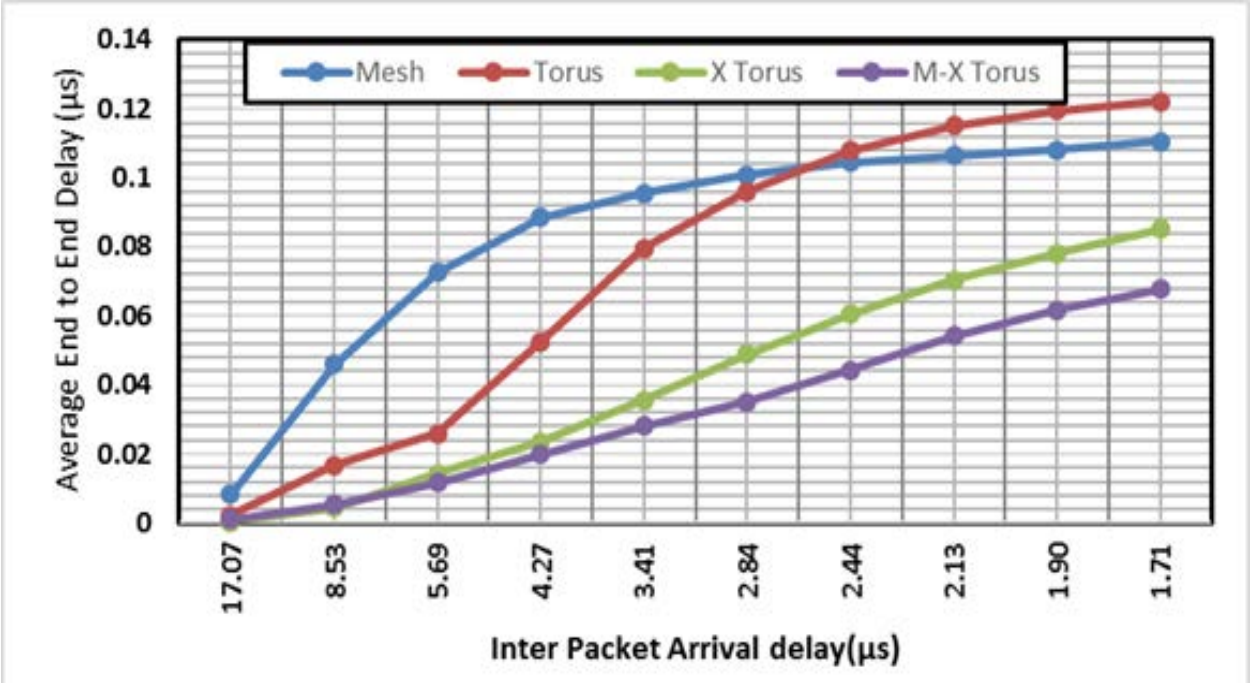

Figure 2.1.7 Average Delay on HotspotTraffic

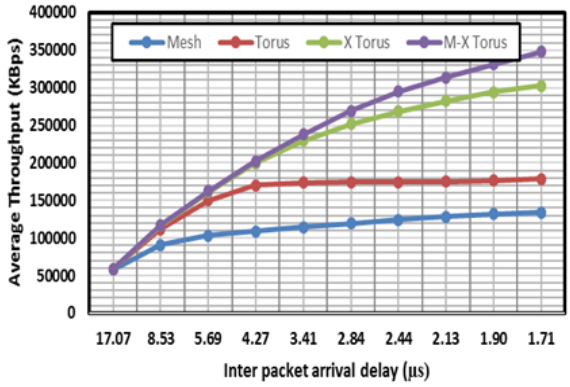

Figure 2.1.8 Average Throughput on Uniform Traffic

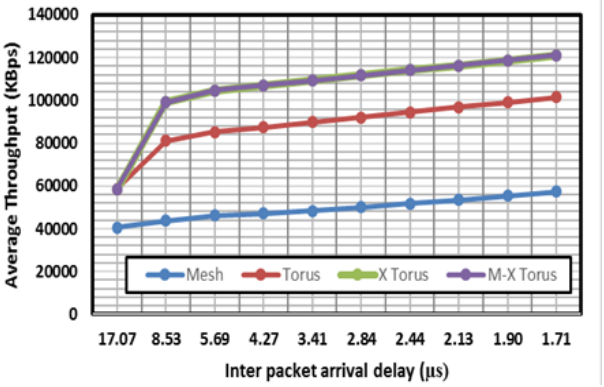

Figure 2.1.9 Average Throughput on Bit Complement Traffic

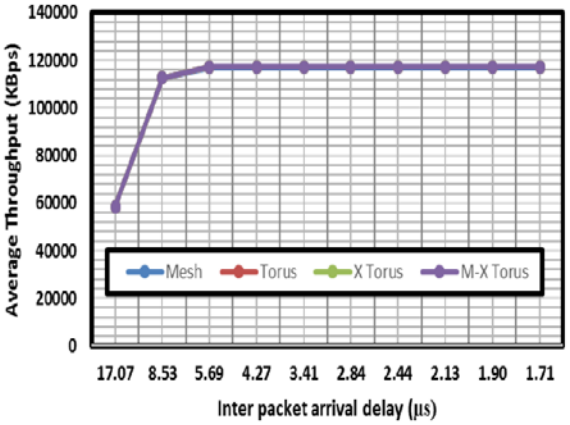

Figure 2.1.10 Average Throughput on Neighbor Traffic

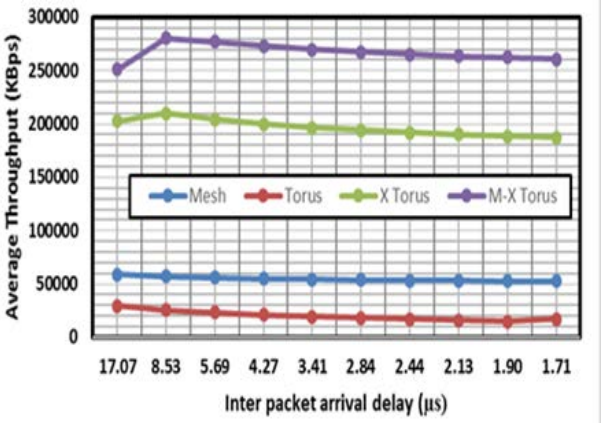

Figure 2.1.11 Average Throughput on Tornado Traffic

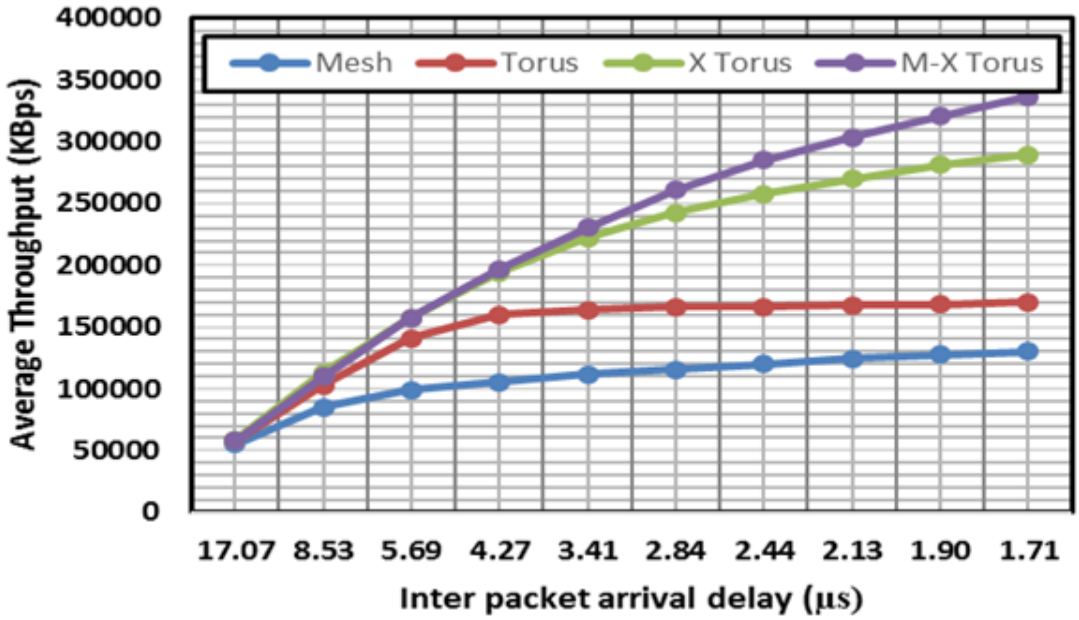

Figure 2.1.12 Average Throughput on Hotspot Traffic

Table 2.1 Simulation Parameters

SN	Network Parameters	Simulation Values
1	Rows	5
2	Columns	5
3	Packet size	1024 bytes
4	Data rate	1 Gbps
5	Simulation time	0.5 s
6	Warm up time	0.5ms
7	Traffic type	Uniform,bit complement,neighbor, tornado,hotspot
8	Link delay	0.1ms
9	Routing algorithm	Table based shortest path(static)

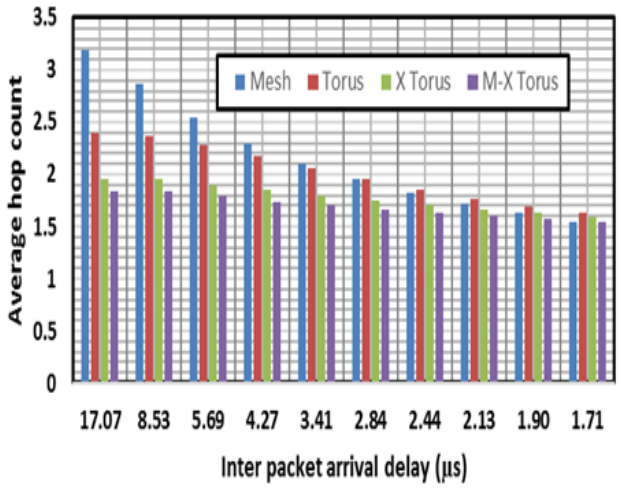

Figure 2.1.13 Average Hop Count on Uniform Traffic

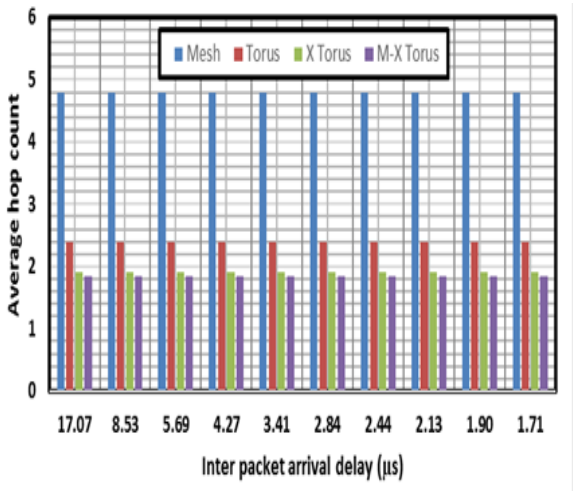

Figure 2.1.14 Average Hop Count on Bit Complement Traffic

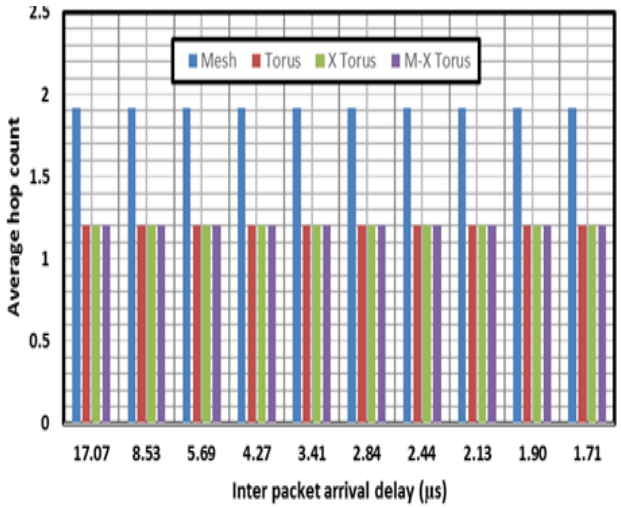

Figure 2.1.15 Average Hop Count on Neighbour Traffic

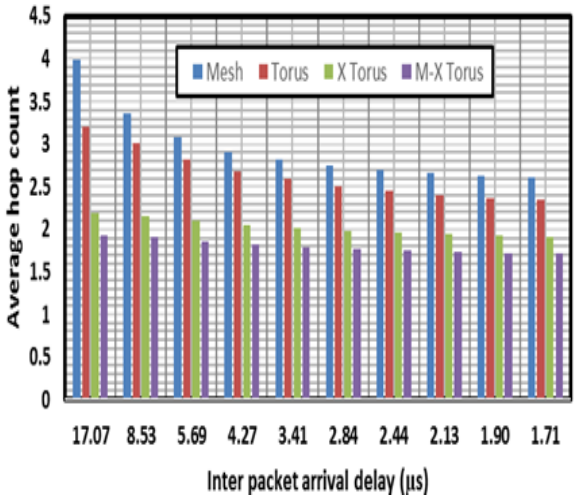

Figure 2.1.16 Average Hop Count on Tornado Traffic

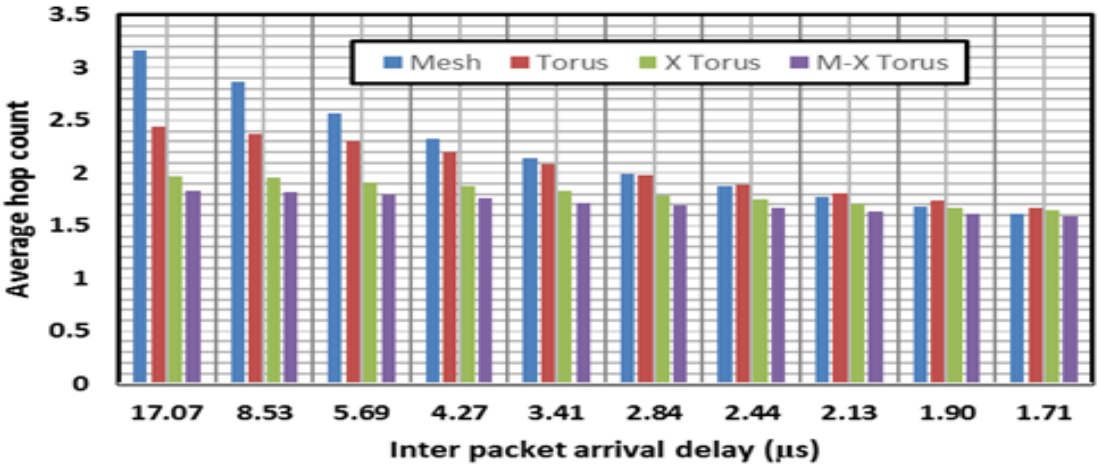

Figure 2.1.17 Average Hop Count on Hotspot Traffic

2.2 To minimize average latency by increasing pathdiversity of Center Concentrated X-Torus Topology.

Center concentrated X-Torus topology reduces the internodal distance between center nodes and all four center nodes of four outer edges. It is the enhanced version of Modified X-Torus[18] topology.

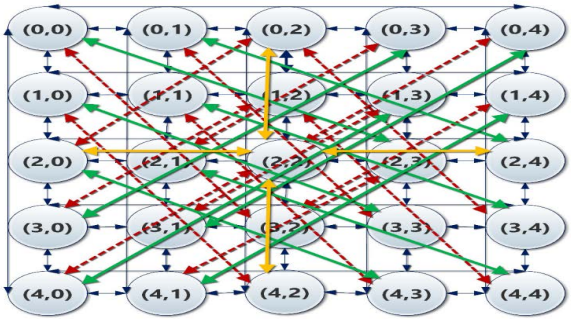

Figure 2.2.1 Center Concentrated X-Torus Topology

Table 2.2 Simulation Parameters

SN	Network Parameters	Simulation Values
1	Rows	5
2	Columns	5
3	Packet size	1024 bytes
4	Data rate	1 Gbps
5	Simulation time	0.5 s
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7	Traffic type	Uniform,bit complement,neighbor, tornado,hotspot
8	Link delay	0.1ms
9	Routing algorithm	Table based shortest path(static)

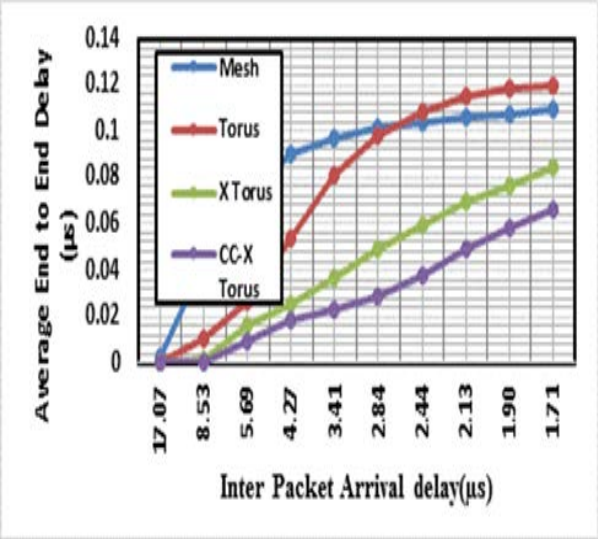

Figure 2.2.2 Average Delay on Uniform Traffic

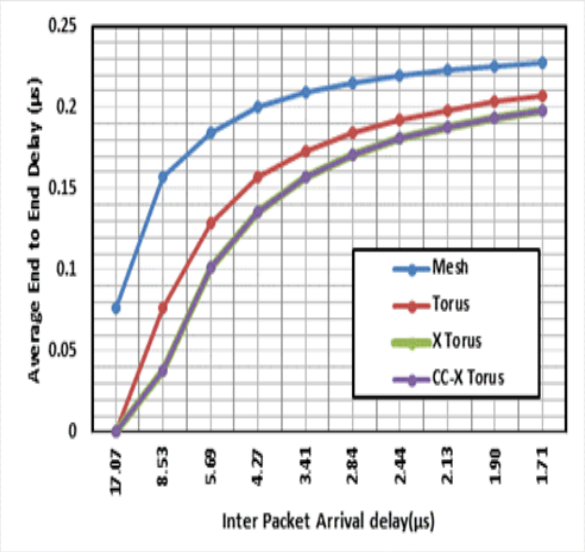

Figure 2.2.3 Average Delay on Bit Complement Traffic

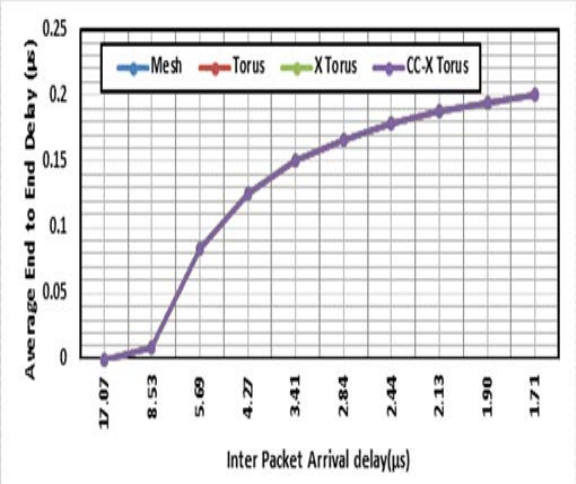

Figure 2.2.4 Average Delay on Neighbor Traffic

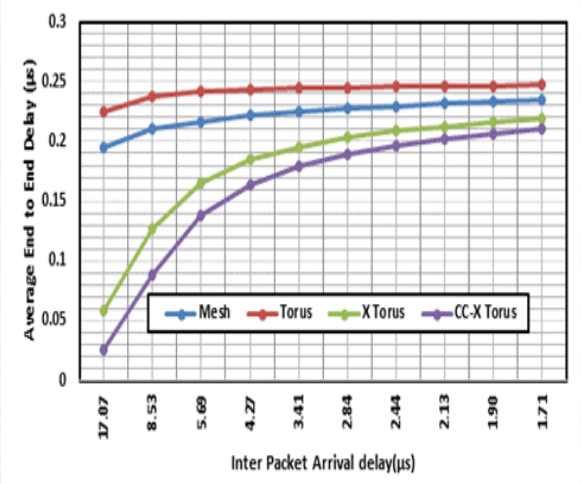

Figure 2.2.5 Average Delay on Tornado Traffic

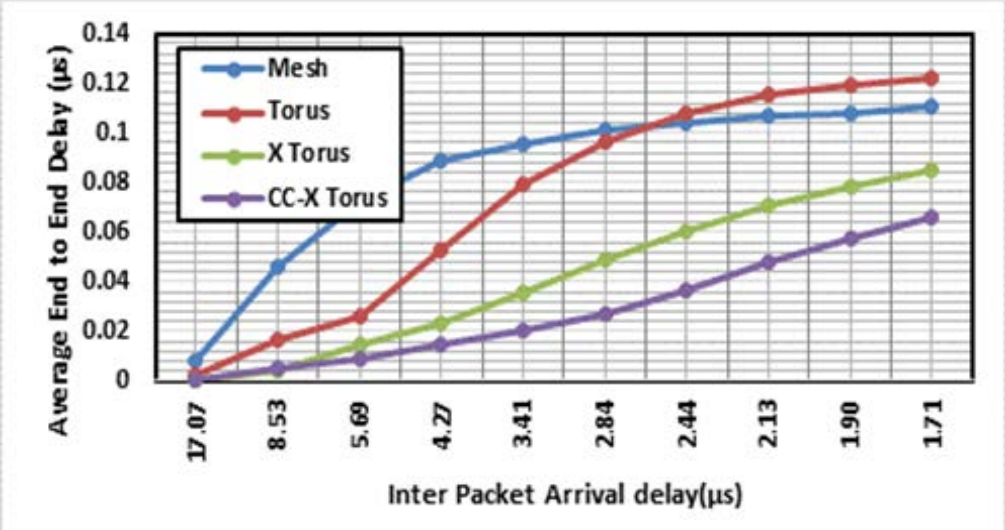

Figure 2.2.6 Average Delay on Hotspot Traffic

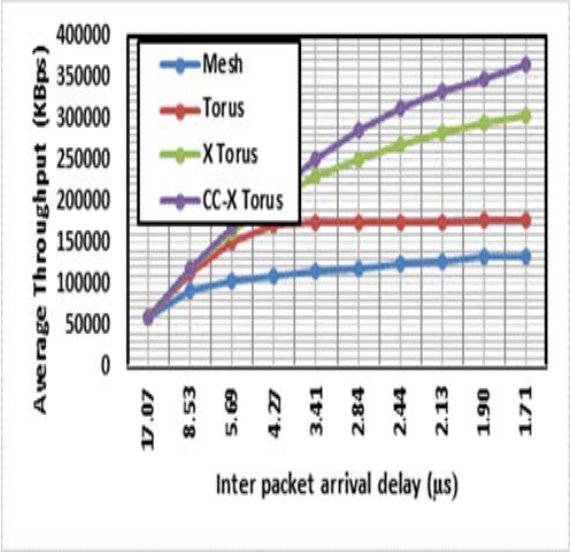

Figure 2.2.7 Average Throughput on Uniform Traffic

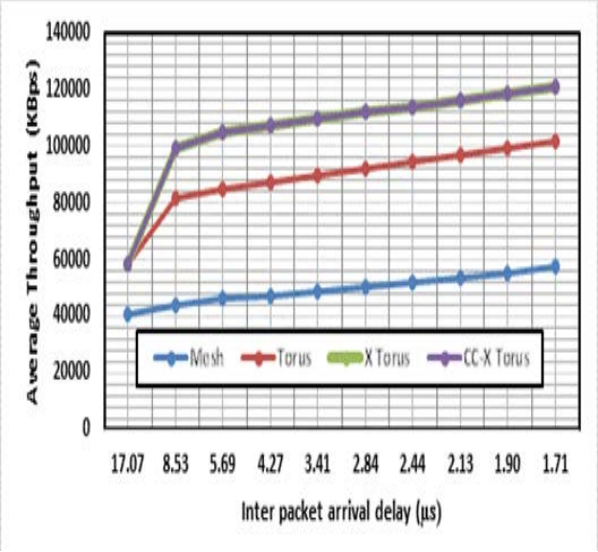

Figure 2.2.8 Average Throughput on Bit Complement Traffic

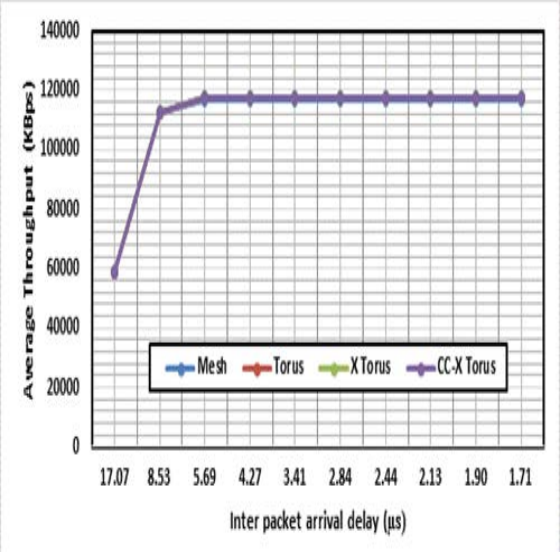

Figure 2.2.9 Average Throughput on Neighbor Traffic

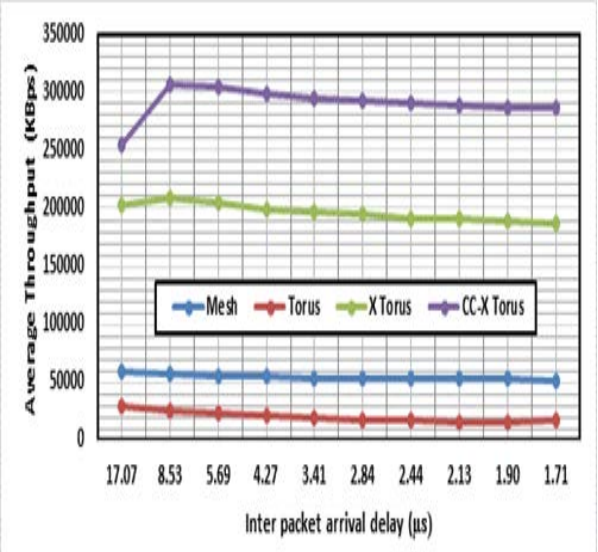

Figure 2.2.10 Average Throughput on Tornado Traffic

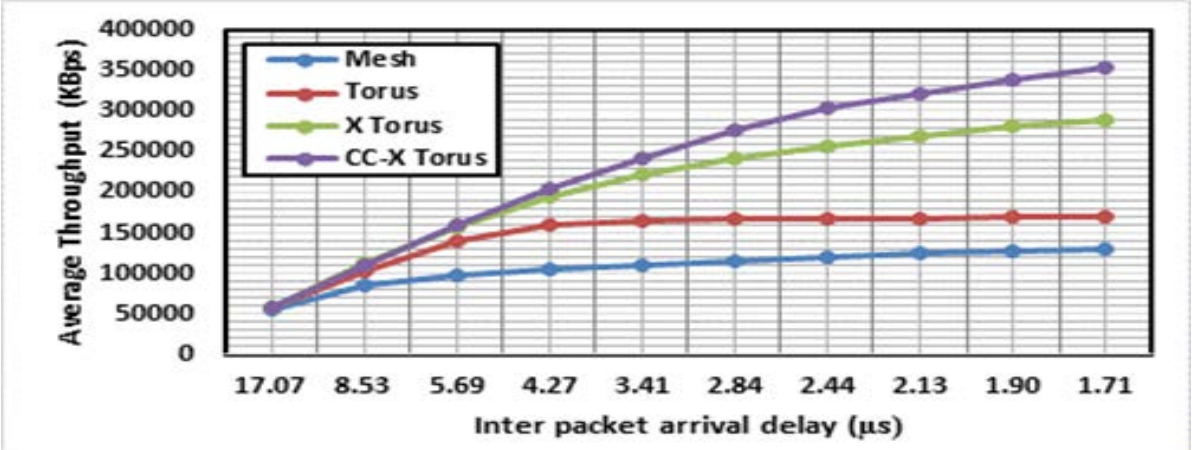

Figure 2.2.11 Average Throughput on Hotspot Traffic

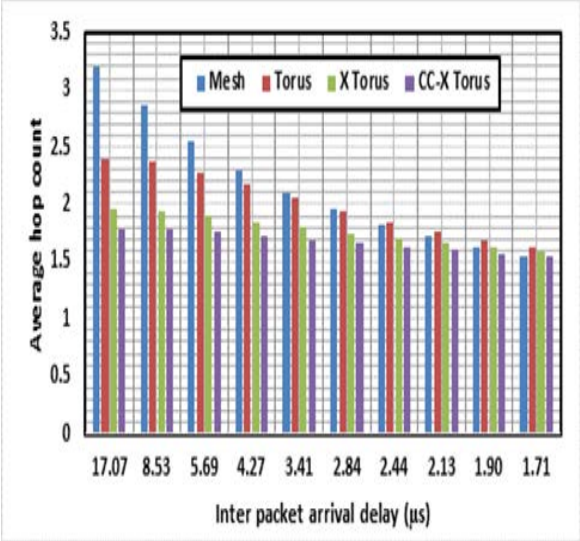

Figure 2.2.12 Average Hop Count on Uniform Traffic

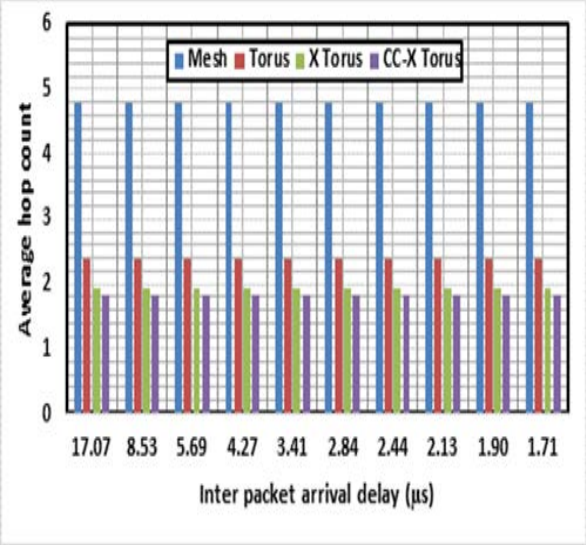

Figure 2.2.13 Average Hop Count on Bit Complement Traffic

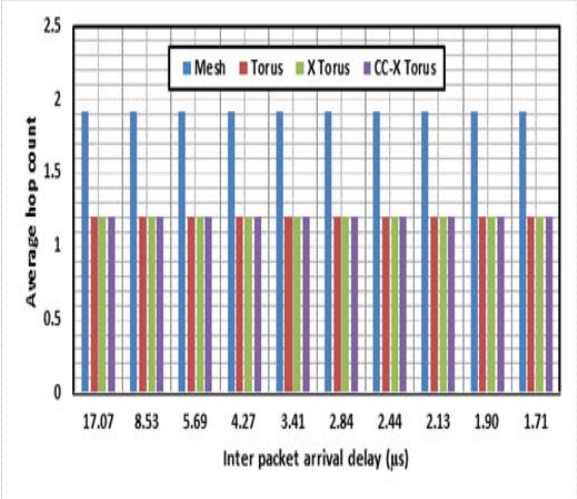

Figure 2.2.14 Average Hop Count on Neighbor Traffic

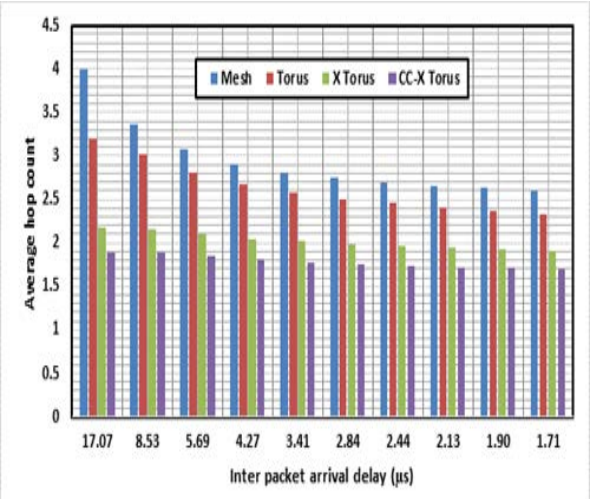

Figure 2.2.15 Average Hop Count on Tornado Traffic

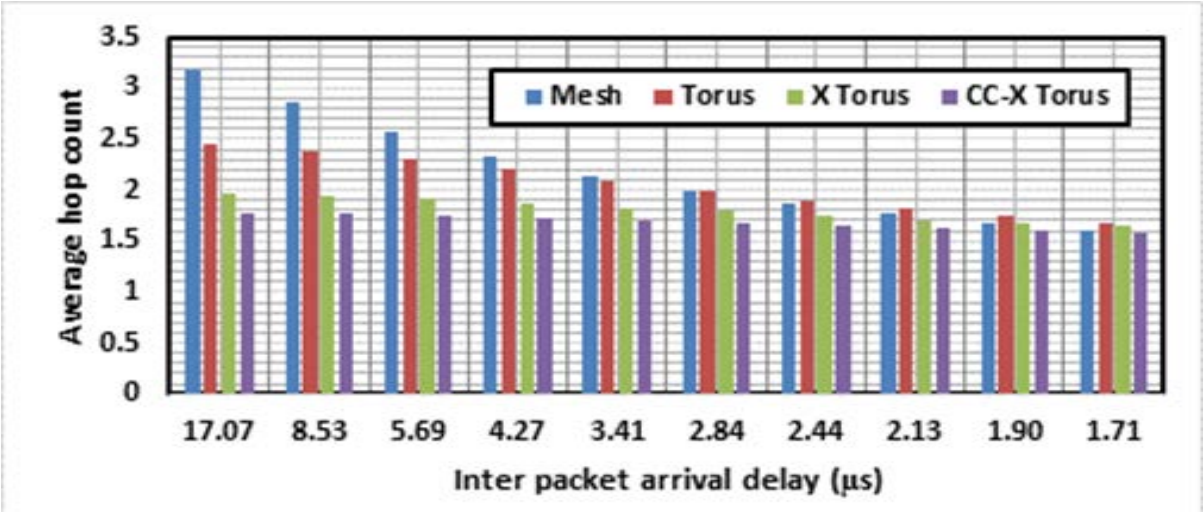

Figure 2.2.16 Average Hop Count on Hotspot Traffic

2.3 To reduce the Average hop count among the nodes by designing Hexagonal X-Torus Topology

Mostly researchers work on three parameters of network. these are topology design, routing algorithm[21], [22] and flow control technique. So here we have focused to design topology which improves overall performance of the network. This is the extension of center concentrated x-torus topology[23]. Here adjacent corners nodes are connected to each other to reduce the hop count by 1 between these node pairs.

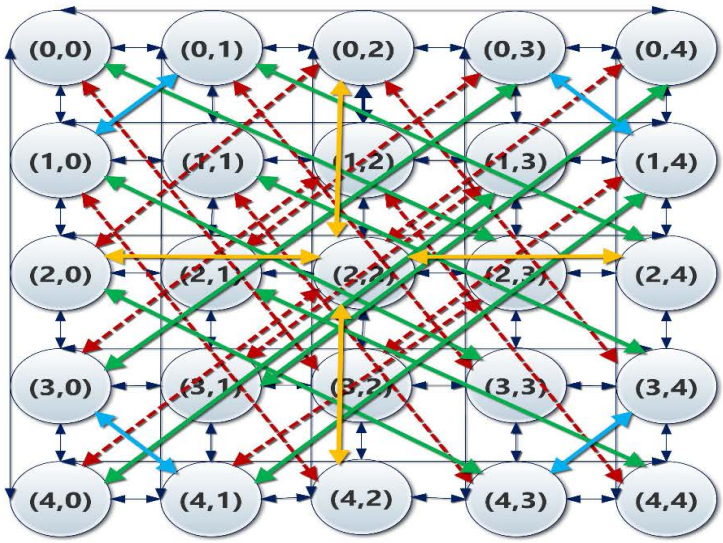

Figure 2.3.1 Hexagonal X-Torus Topology

This is simulated under various traffic patterns and provides better results in terms of latency, throughput as well as hop count.

Table 2.3 Simulation Parameter*s*

SN	Network Parameters	Simulation Values
1	Rows	5
2	Columns	5
3	Packet size	1024 bytes
4	Data rate	1 Gbps
5	Simulation time	0.5 s
6	Warm up time	0.5ms
7	Traffic type	Uniform,bit complement,neighbor, tornado,hotspot
8	Link delay	0.1ms
9	Routing algorithm	Table based shortest path(static)

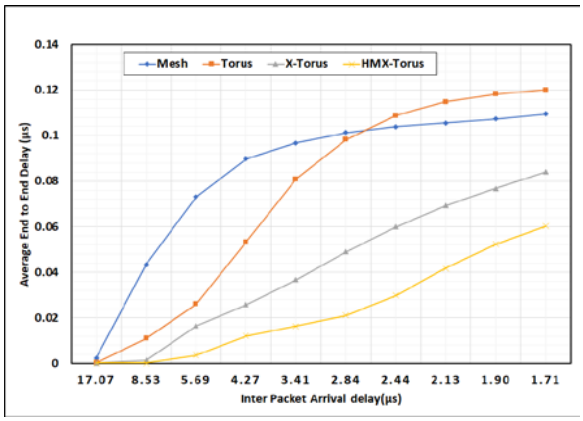

Figure 2.3.2 Average Delay on Uniform Traffic

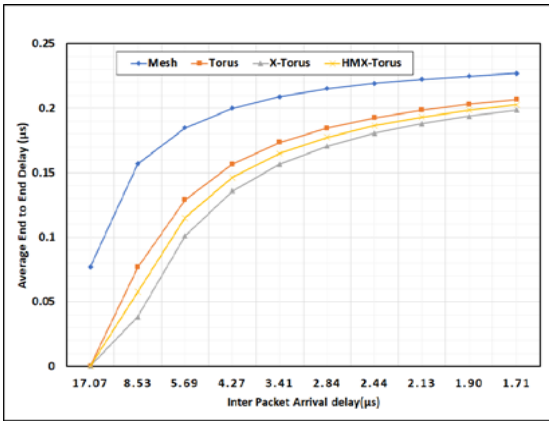

Figure 2.3.3 Average Delay on Bit Complement Traffic

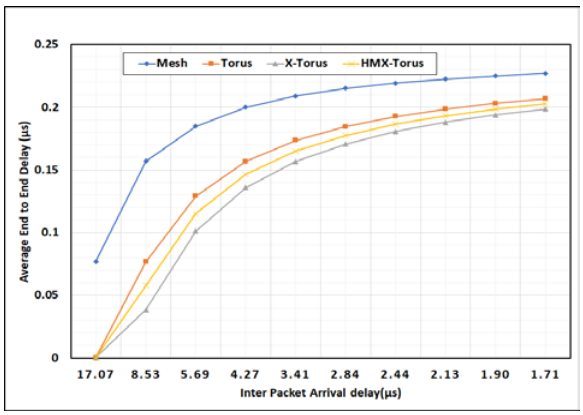

Figure 2.3.4 Average Delay on Neighbor Traffic

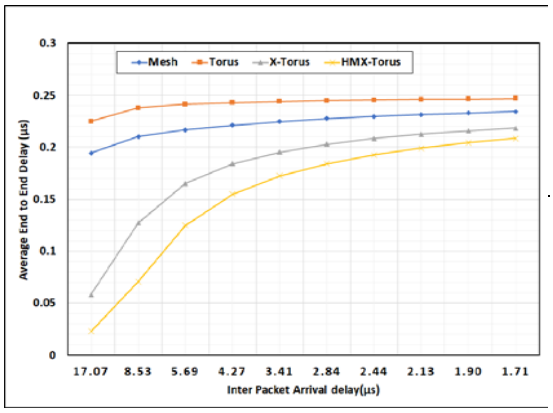

Figure 2.3.5 Average Delay on Tornado Traffic

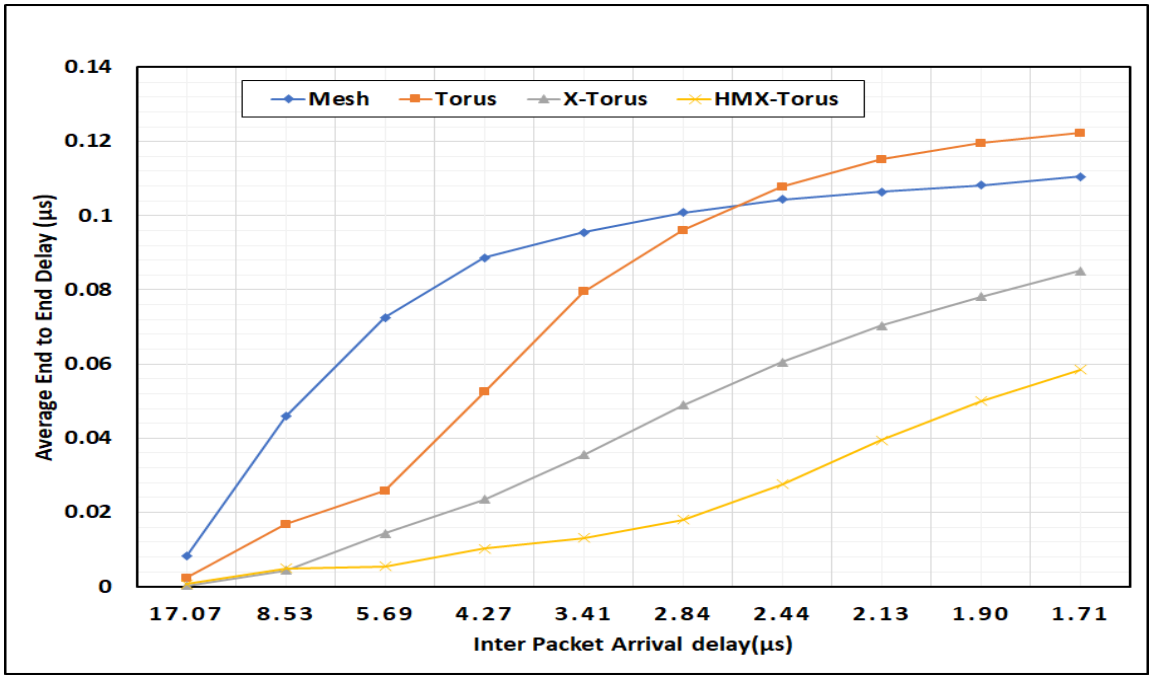

Figure 2.3.6 Average Delay on Hotspot Traffic

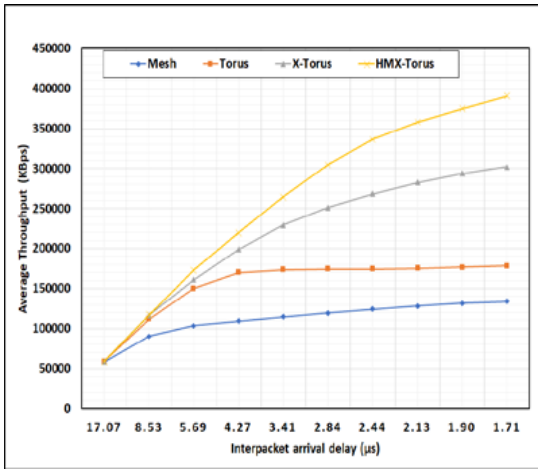

Figure 2.3.7 Average Throughput on Uniform Traffic

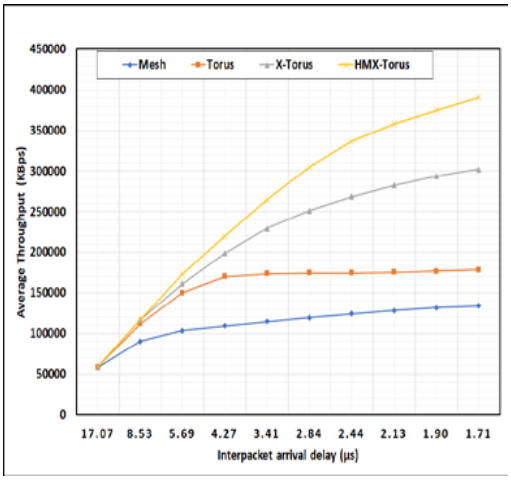

Figure 2.3.8 Average Throughput on Bit Complement Traffic

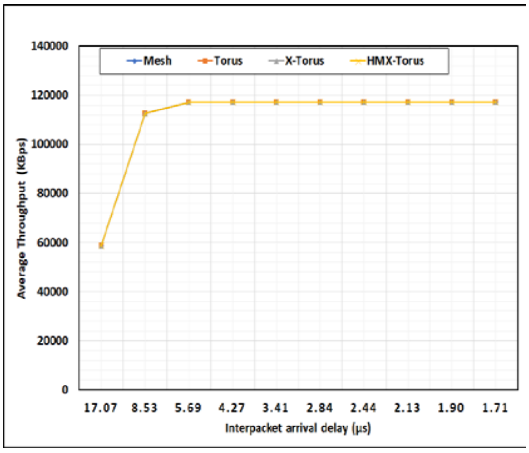

Figure 2.3.9 Average Throughput on Neighbor Traffic

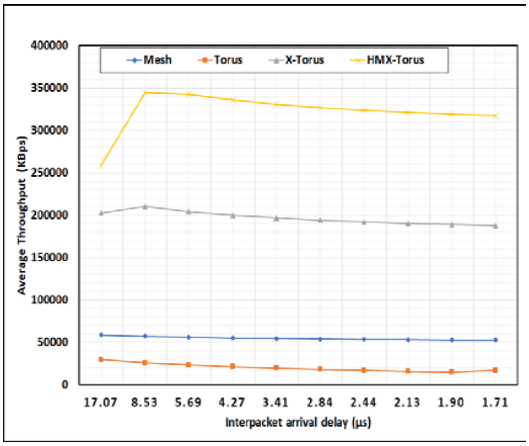

Figure 2.3.10 Average Throughput on Tornado Traffic

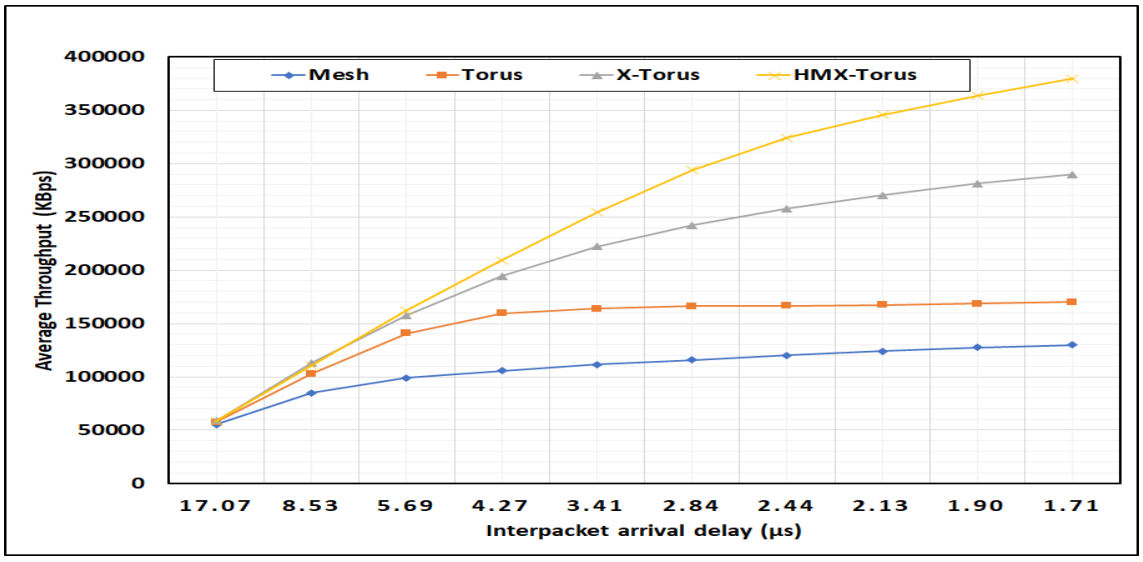

Figure 2.3.11 Average Throughput on Hotspot Traffic

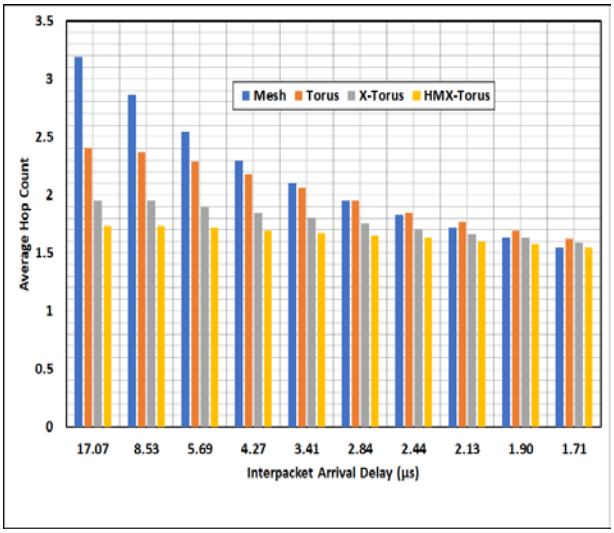

Figure 2.3.12 Average Hop Count on Uniform Traffic

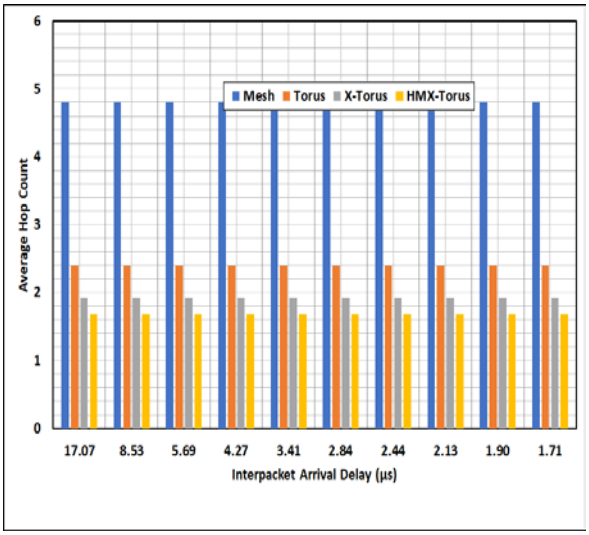

Figure 2.3.13 Average Hop Count on Bit Complement Traffic

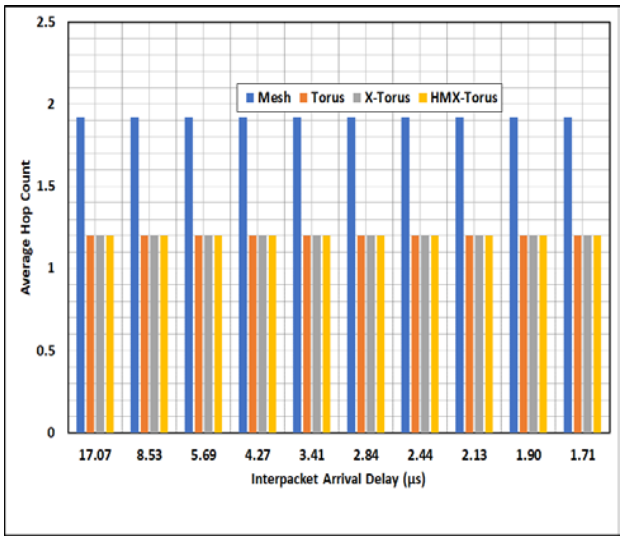

Figure 2.3.14 Average Hop Count on Neighbor Traffic

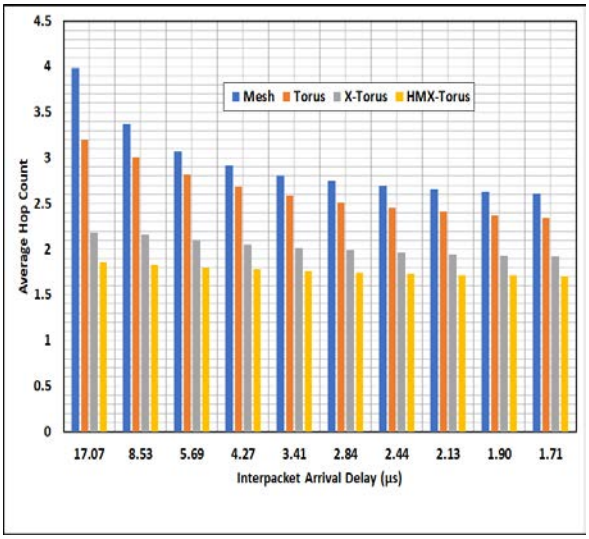

Figure 2.3.15 Average Hop Count on Tornado Traffic

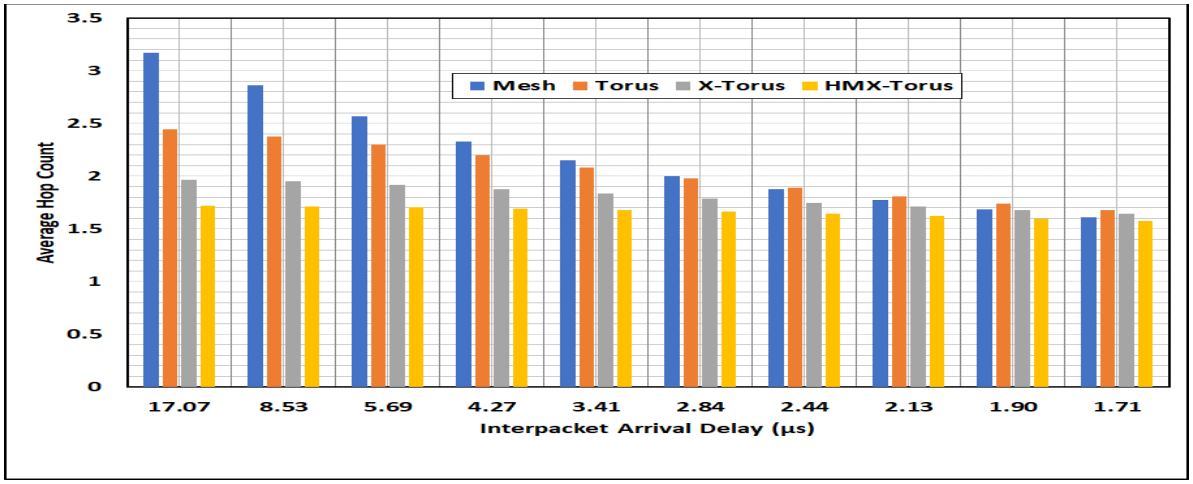

Figure 2.3.16 Average Hop Count on Hotspot Traffic

2.4 To improve the throughput, latency and hop count by modifying D-Torus Network

Modified D-Torus plays an important role to reduce inter node distance and improve hop count, delay as well as throughput. In the proposed topology opposite corner nodes are connected by extra link which reduces more hop count. Thus, results in reduction of delay. This is simulated under various traffic patterns with other existing topologies like mesh, Xmesh, Torus,and Dtorus[7], [24], [25].

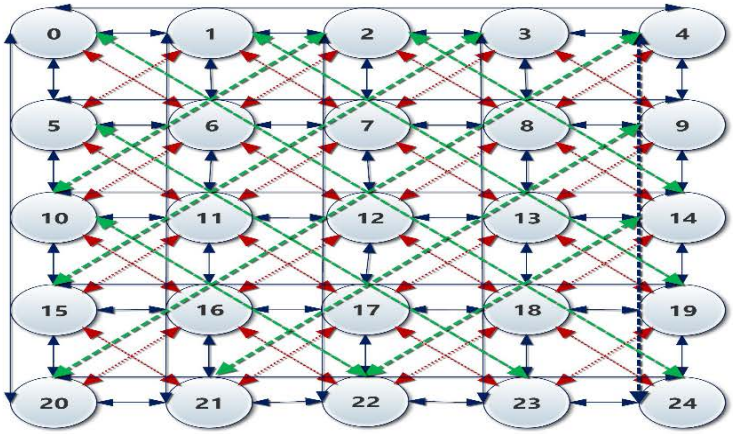

Figure 2.4.1 Modified Diagonal Torus Topology

Table 2.4 Simulation Parameters

SN	Network Parameters	Simulation Values
1	Rows	5
2	Columns	5
3	Packet size	1024 bytes
4	Data rate	1 Gbps
5	Simulation time	0.5 s
6	Warm up time	0.5ms
7	Traffic type	Uniform,bit complement,neighbor , tornado,hotspot
8	Link delay	0.1ms
9	Routing algorithm	Table based shortest path(static)

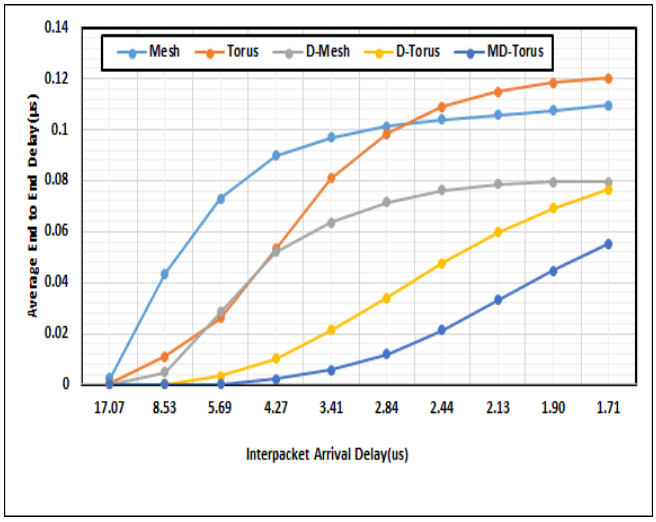

Figure 2.4.2 Average Delay on Uniform Traffic

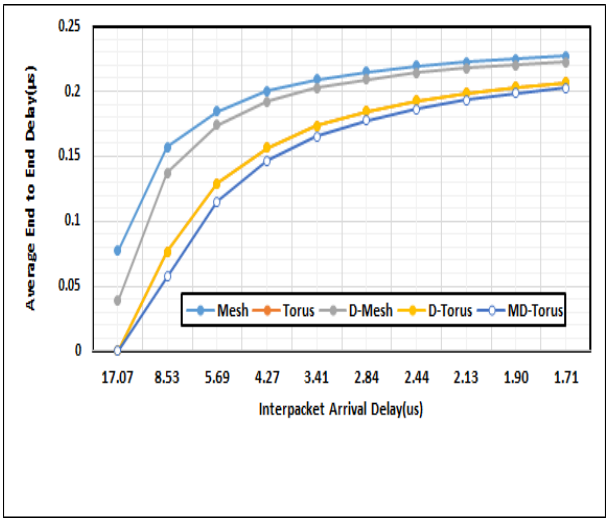

Figure 2.4.3 Average Delay on Bit Complement Traffic

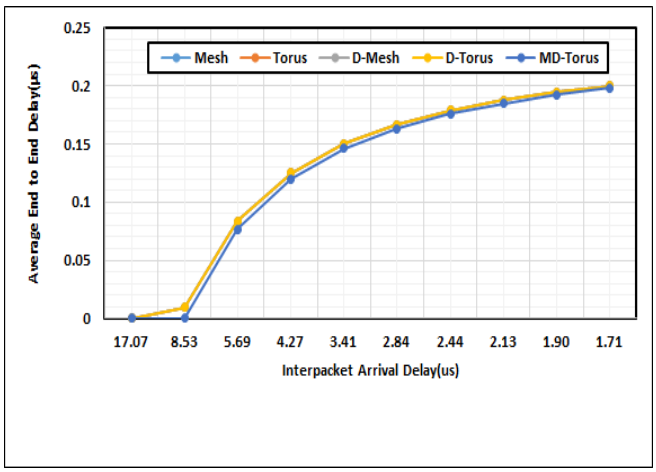

Figure 2.4.4 Average Delay on Neighbor Traffic

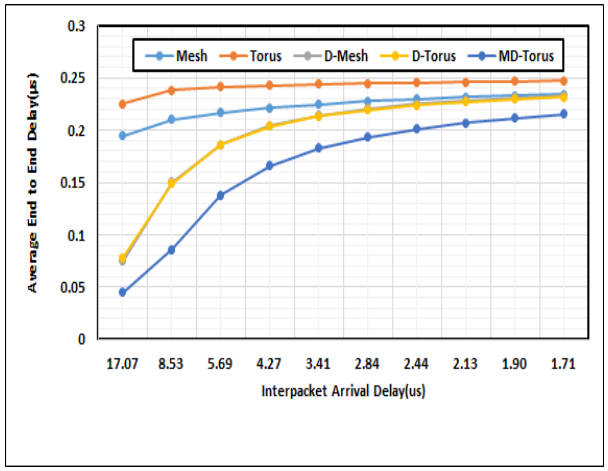

Figure 2.4.5 Average Delay on Tornado Traffic

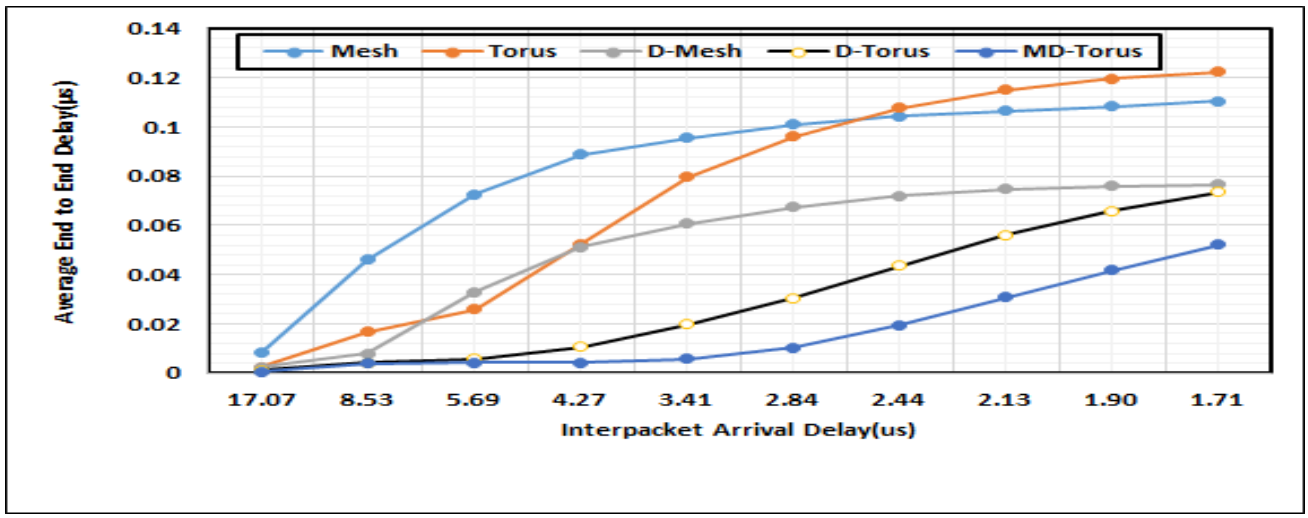

Figure 2.4.6 Average Delay on Hotspot Traffic

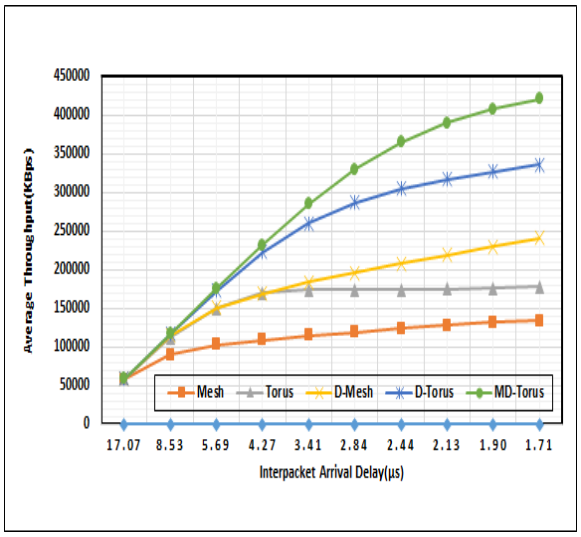

Figure 2.4.7 Average Throughput on Uniform Traffic

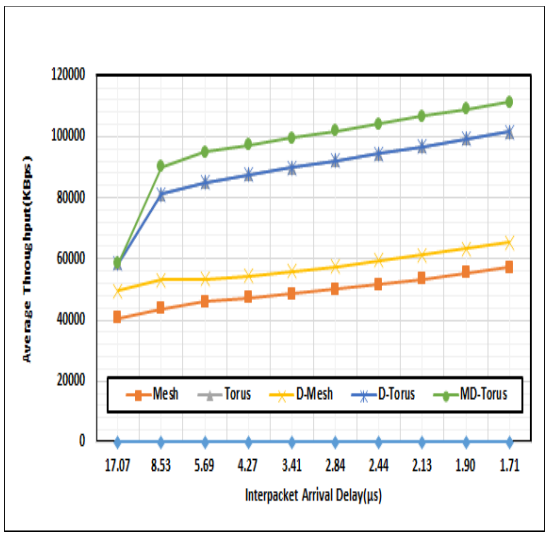

Figure 2.4.8 Average Throughput on Bit Complement Traffic

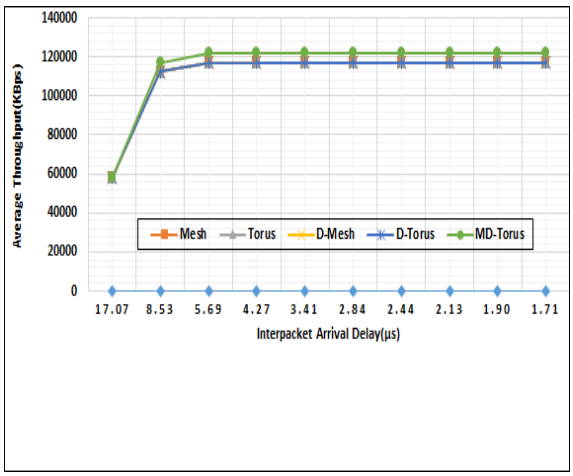

Figure 2.4.9 Average Throughput on Neighbor Traffic

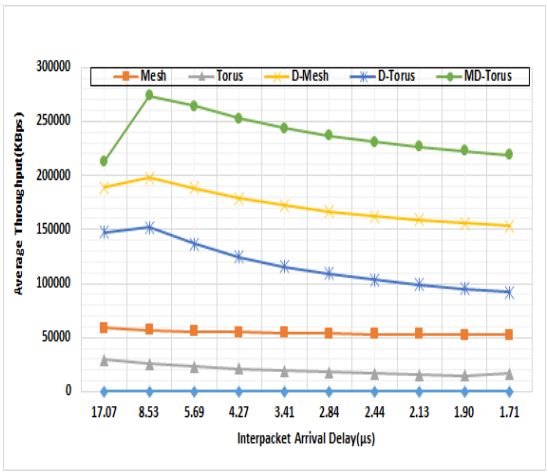

Figure 2.4.10 Average Throughput on Tornado Traffic

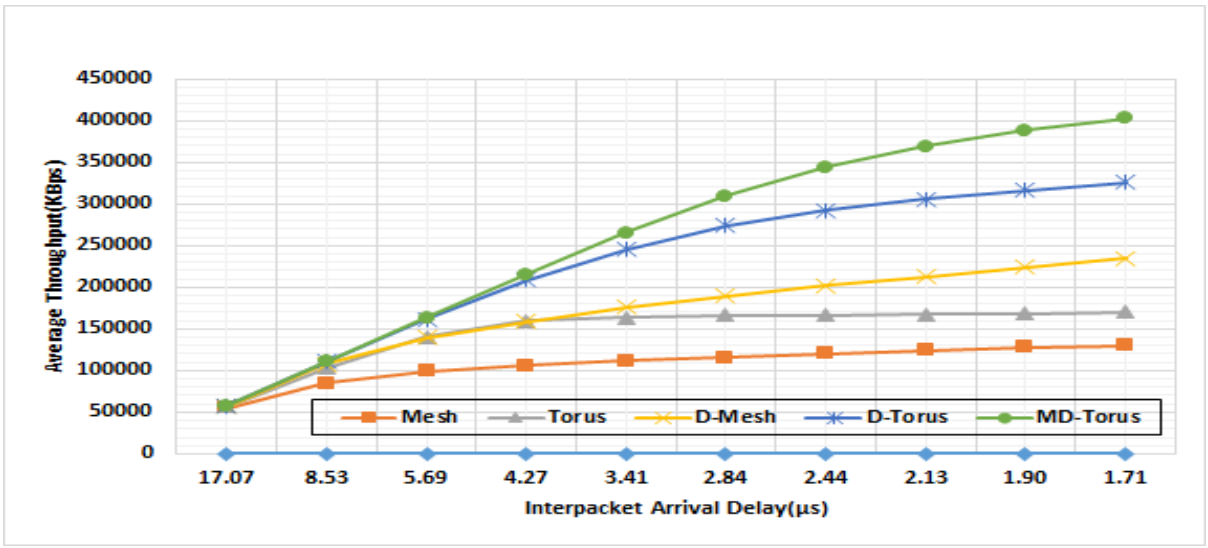

Figure 2.4.11 Average Throughput on Hotspot

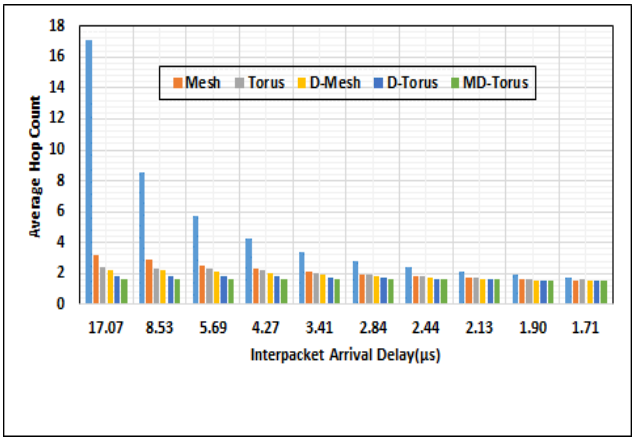

Figure 2.4.12 Average Hop Count on Uniform Traffic

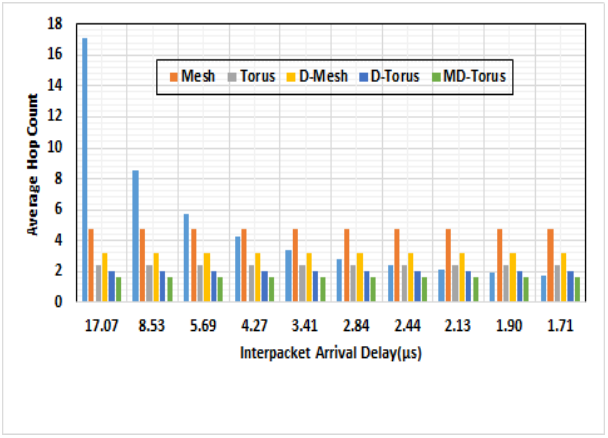

Figure 2.4.13 Average Hop Count on Bit Complement Traffic

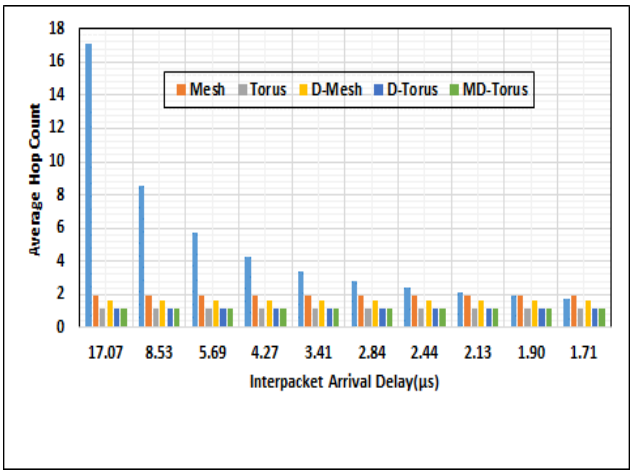

Figure 2.4.14 Average Hop Count on Neighbor Traffic

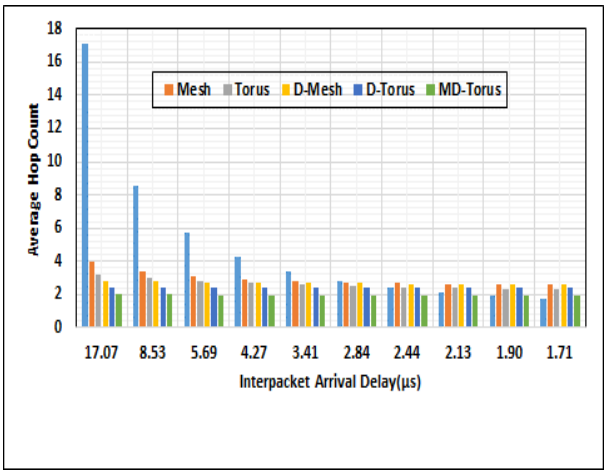

Figure 2.4.15 Average Hop Count on Tornado Traffic

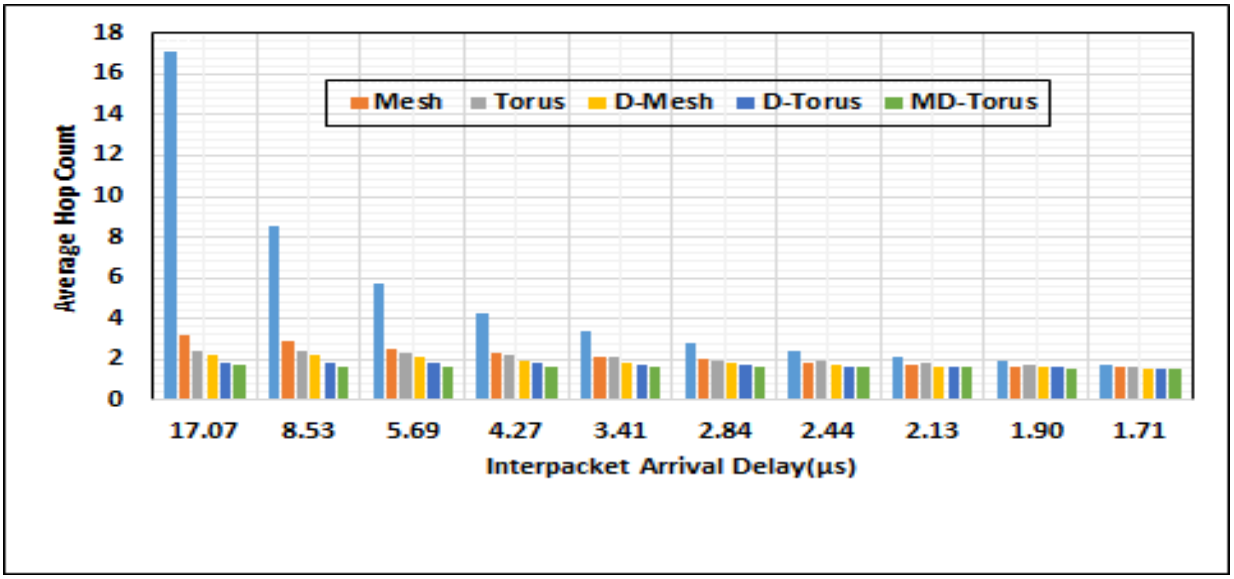

Figure 2.4.16 Average Hop Count on Hotspot Traffic

2.5 To Compare Different topologies using Distance vector and Link State Routing Protocols

Routing algorithms[26] are one of the key factor which affects the network performance. Basically, routing algorithm decides the shortest path taken by source to send packets to destination node over communication channel. Here we have considered four topologies[27] and simulated using NS2 simulator[14]. Simulation parameters taken are as follows.

Table 2.5 Simulation Parameters

Topology	Mesh, Torus, X-Torus, MX-Torus
Link	Link type: duplex-link Queue type: Drop Tail Capacity: 1Mbps Propagation Delay: 10ms Queue Size: 50
Agent	Source: UDP Destination: NULL Packet size: 1500 bytes
Application	Application Type: CBR Start time: 0.5 ms Stop time: 4.5 ms Packet size: 1000 Rate: 1Mbps Interval: 0.005 ms
Traffic	Constant Bit Rate(CBR) Exponential FTP
Simulation Time	5ms

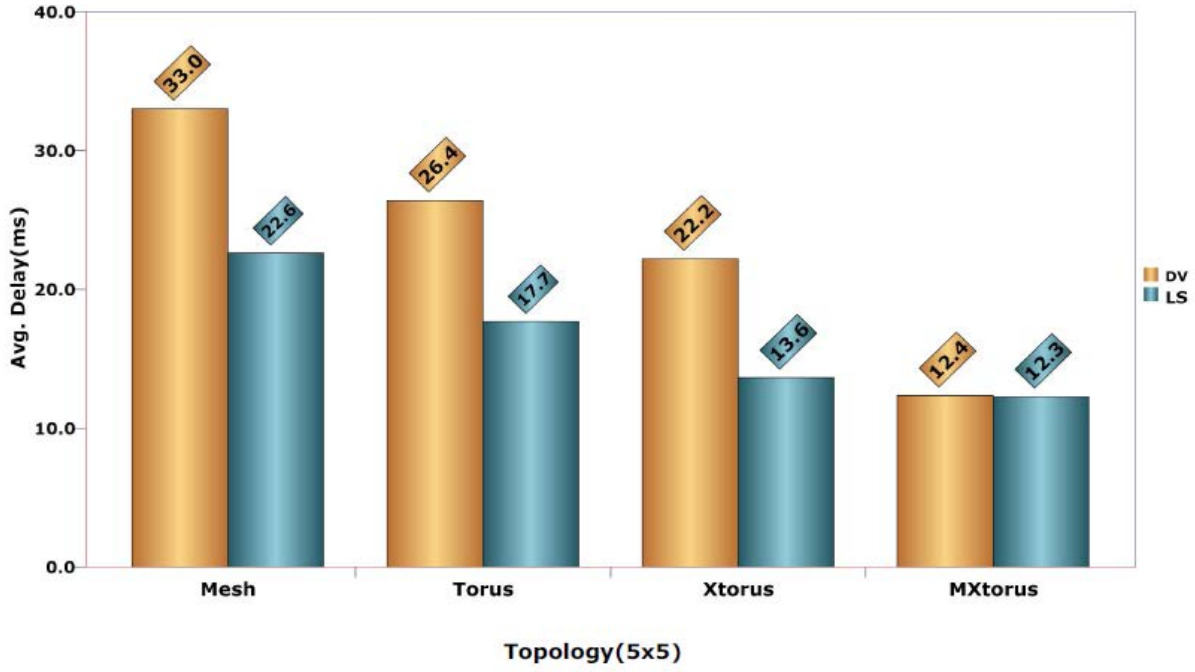

Figure 2.5.1 Average Delay on CBR Traffic

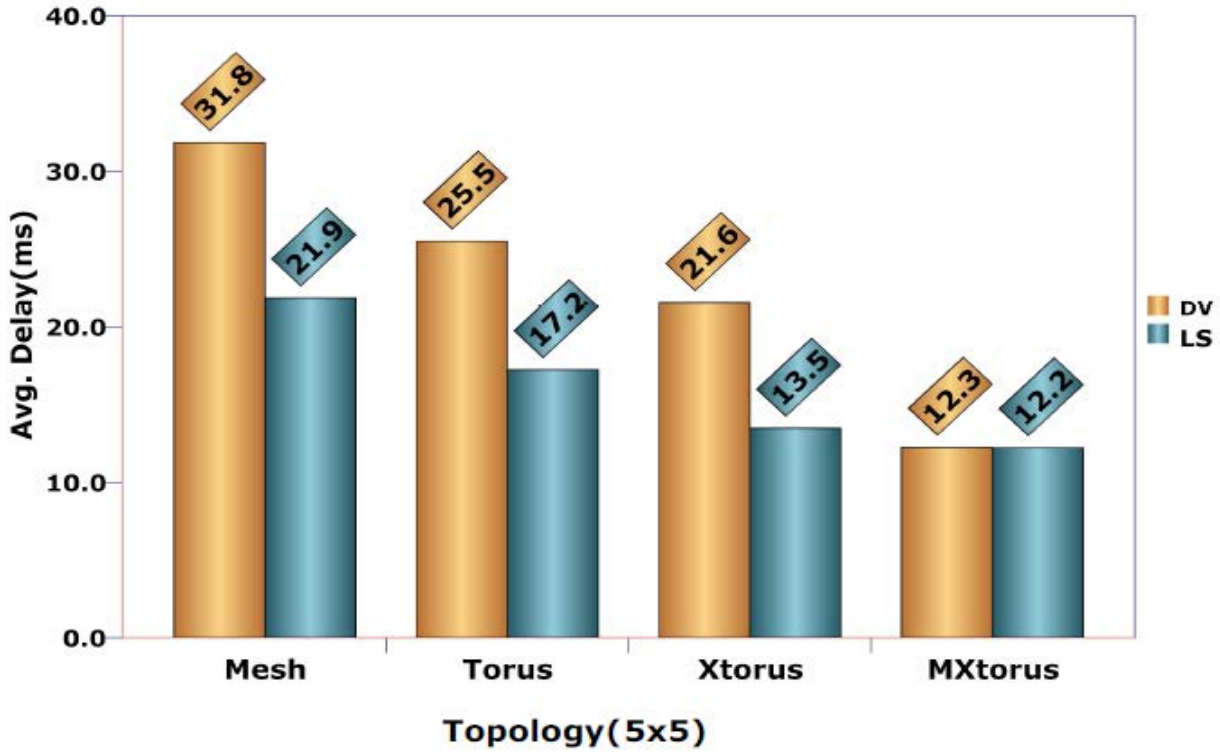

Figure 2.5.2 Average Delay on Exponential Traffic

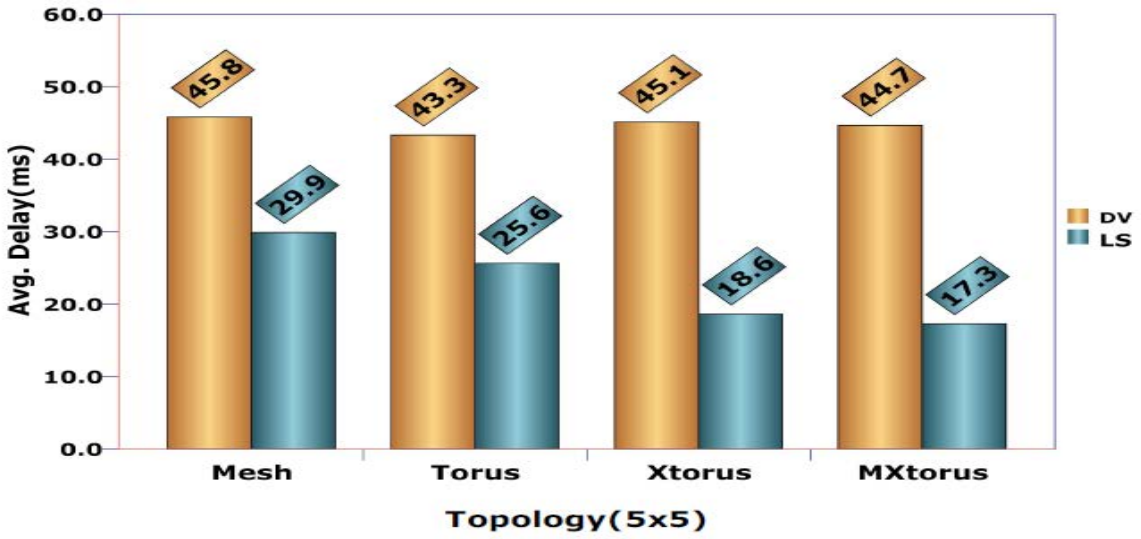

Figure 2.5.3 Average Delay on FTP Traffic

Table 2.5 Percentage Improvement Over Different Traffic

Traffic	Topology	Delay in packets (ms)		Percentage change
		Distance Vector Routing Algorithm	Link State Routing Algorithm	
CBR	Mesh	33.0609	22.6257	31.56357
	Torus	26.3977	17.7079	32.91878
	X-Torus	22.2061	13.6487	**38.53626**
	MX-Torus	12.3596	12.2713	0.714424
Exponential	Mesh	31.8332	21.8617	31.32421
	Torus	25.5041	17.2426	32.39283
	X-Torus	21.5586	13.482	**37.46347**
	MX-Torus	12.2518	12.2214	0.248127
FTP	Mesh	45.828	29.885	34.3478
Application	Torus	43.316	25.6422	40.8020
	X-Torus	45.1258	18.6432	58.6861
	MX-Torus	44.6616	17.294	**61.2776**

3 CONCLUSION

To achieve the high performance for the throughput, latency and hop count constraining to topological properties of the network the four network topologies have been suggested. These topologies improve quality of services as well as topological properties like reducing diameter, increasing path diversity and higher bisection bandwidth.From the results obtained in last objective, we can conclude that the performance of link state routing algorithm is better in comparison to that of the Distance vector routing algorithm. The other significant advantage of the link state routing algorithm is that it initially maintains the knowledge of its neighbors instead doing the path exploration of the complete topology. In future, we are planning to test the topologies under different load conditions on the routing algorithms. Also, we want to generate the experimental setup in which we can have simultaneous communication between the different nodes.

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LIST OF PUBLICATIONS

Journal Publications:

Published:-

1. Dinesh Kumar, Vivek Kumar Sehgal, Nitin, "A Modified X-Torus Topology for Interconnection Network," Journal of Telecommunication, Electronic and Computer Engineering (JTEC), 9(3-6), 49-54 (Free Scopus).
2. Dinesh Kumar, Vivek Kumar Sehgal, Nitin, "Center Concentrated X-Torus Topology," Journal of Telecommunication, Electronic and Computer Engineering (JTEC) 9(3-6), 55-60 (Free Scopus).

Communicated:-

1. Dinesh Kumar, Vivek Kumar Sehgal, Nitin, "A Hexagonal X-Torus Topology for Interconnection Network ", Springer Computing (SCI, Communicated).

Conference Publications:

Paper Presented:-

1. Dinesh Kumar, Vivek Kumar Sehgal, Nitin, "A Modified X-Torus Topology for Interconnection Network," RICSIT 2017 HPU Shimla.
2. Dinesh Kumar, Vivek Kumar Sehgal, Nitin, "Center Concentrated X-Torus Topology," RICSIT 2017 HPU Shimla.
3. Dinesh Kumar, Vivek Kumar Sehgal, Nitin, "Performance Evaluation of Routing Algorithms on Network on Chips," Proceedings of the 12th INDIACom, INDIACom-2018, IEEE Conference, pp 2060-2064.